Space Technology Research Grants

Optimizing Materials for Energy Harvesting on Interplanetary Return Missions

Completed Technology Project (2013 - 2017)

Project Introduction

Manned interplanetary missions will only be desirable once the ability to return is established. Even using improved fuel technologies we have not resourced the fuel requirement for return missions to our nearest terrestrial neighbors. Energy harvesting in Outer Space or on another planet is imperative for return mission success, as it is impossible with current Earth-based fuel technologies to supply an outgoing mission to our closest neighbor planets with enough fuel for return. Thermophotovoltaic (TPV) devices, with a theorized maximal efficiency of 85 % conversion of incident sunlight to electricity [1], are ideal for such harvesting. Thus, the work I propose will investigate performance parameters of select TPV materials. Specifically, I will study how the optical absorption, thermal emission, electronic energy conversion and thermal transport properties are related to the structural features of TPV materials in the presence of photon wavelengths abundant in the universe. Through an in-depth, coupled experimental and theoretical, study the relationship between amorphous material structure (i.e., atomic density and fractal dimension) and optical absorption, thermal emission, electronic conversion and thermal transport properties will be determined. The results will establish the governing materials physics to further guide material selection and device design for efficient electromagnetic harvesting cells to be used for constant refuel on interplanetary missions. We will investigate organic semiconducting polymers including but not limited to: PCBM, P3HT, and P3HT:PCBM blend thin films. Due to their small band gaps these materials have an extremely high capacity for absorption in the visible and near-IR spectra, wavelengths abundant on the Martian surface and in interplanetary space. These materials also offer low thermal conductivities and controllable fractal-dendritic growth [2]. With further improvements to energy conversion efficiency, these amorphous organic materials offer cost-effective and reliable alternatives to current state-of-the-art TPV device materials. Optical absorption coefficients, electronic scattering rates and electronic recombination times will be measured with sub-picosecond optical techniques. The sub-picosecond resolution of absorption and electron scattering rate measurements will offer direct insight into the optical and electronic processes. Emission spectra of the samples will be monitored with optical emission spectrometry. Thermal conductivity and the thermal boundary conductance of the systems will be measured with a sub-picosecond thermoreflectance technique. With these measurements the interplay between the electronic scattering processes and the thermal transport will be evidenced. Temperature dependent measurements will be conducted over the range of 10-1800 K, as facilitated with an optically accessible cryostat. Further, experimental data will be analyzed with atomistic models to develop analytical and phenomenological theories. The atomistic model development will focus on quantum mechanical non-equilibrium Green's functions (NEGF). NEGF modeling constructs the material from atomic components and is therefore the ideal approach to study the effects of specific structural arrangements on electron excitation, scattering and recombination. The trends determined with the NEGF approach

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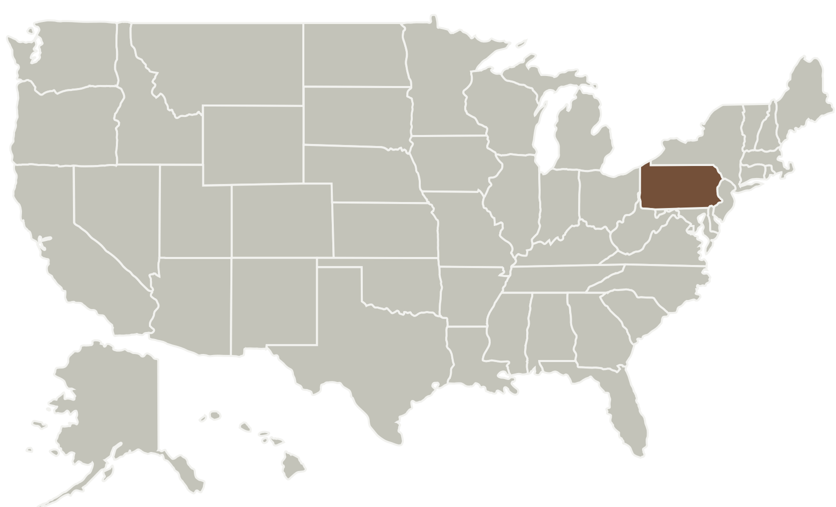
will be directly compared to the trends observed in the experimental data to determine the intricacies in the relationship between atomic arrangement and electronic activity on an atomistic level. [1] Harder, Nils-Peter, and Peter Würfel. Theoretical limits of thermophotovoltaic solar energy conversion. Semiconductor science and technology 18(5):S151, 2003. [2] Liu, Hui, and Petra Reinke. C60 thin film growth on graphite: Coexistence of spherical and fractal-dendritic islands. The Journal of chemical physics, 124: 164707, 2006.

Anticipated Benefits

Manned interplanetary missions will only be desirable once the ability to return is established. Even using improved fuel technologies we have not resourced the fuel requirement for return missions to our nearest terrestrial neighbors. Energy harvesting in Outer Space or on another planet is imperative for return mission success, as it is impossible with current Earth-based fuel technologies to supply an outgoing mission to our closest neighbor planets with enough fuel for return. Thermophotovoltaic (TPV) devices, with a theorized maximal efficiency of 85 % conversion of incident sunlight to electricity [1], are ideal for such harvesting. Thus, this workinvestigates performance parameters of select TPV materials. Specifically, I will study how the optical absorption, thermal emission, electronic energy conversion and thermal transport properties are related to the structural features of TPV materials in the presence of photon wavelengths abundant in the universe.

Primary U.S. Work Locations and Key Partners



Organizational Responsibility

Responsible Mission Directorate:

Space Technology Mission Directorate (STMD)

Lead Organization:

Carnegie Mellon University

Responsible Program:

Space Technology Research Grants

Project Management

Program Director:

Claudia M Meyer

Program Manager:

Hung D Nguyen

Principal Investigator:

David Laughlin

Co-Investigator:

Caroline S Gorham

Organizations Performing Work	Role	Type	Location
Carnegie Mellon University	Lead Organization	Academia	Pittsburgh, Pennsylvania

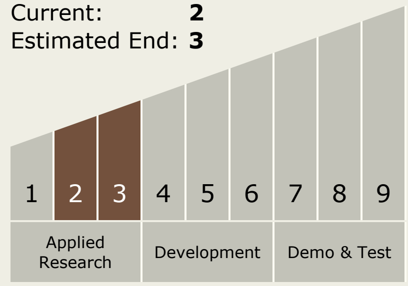
Primary U.S. Work Locations
Pennsylvania

Project Website:

https://www.nasa.gov/directorates/spacetech/home/index.html

Technology Maturity (TRL)

Start: **2**
Current: **2**
Estimated End: **3**



Technology Areas

Primary:

- TX12 Materials, Structures, Mechanical Systems, and Manufacturing
  - └─ TX12.1 Materials
    - └─ TX12.1.6 Materials for Electrical Power Generation, Energy Storage, Power Distribution and Electrical Machines

Target Destinations

Mars, Others Inside the Solar System, Foundational Knowledge